Programmed Oscillator Software Development for High-Doppler-Rate Orbiting Spacecraft

R. Emerson
Communications Systems Research Section

The programmed oscillator (PO) can be used to track spacecraft signals. Orbiting spacecraft impose additional requirements upon the ephemeris used by the programmed oscillator. Modifications to the existing programmed oscillator were made. Experience with the tracking of Mariner Mars 1971 (MM'71) during superior conjunction shows that a receiver, assisted by the signal from the programmed oscillator, permits the tracking of high-doppler-rate signals close to the threshold of the receiver. The advantages of programmed oscillator assisted receiver operation include the reduction of stress upon the loop voltage-controlled oscillator (VCO), obviating the need for more than one VCO per receiver, and the provision of an acquisition aid for the receiver operators. This was demonstrated during the recent Mariner 1971 solar occultation, where no other tracking method could maintain lock.

I. Introduction

This article describes the modifications made to the programmed oscillator (PO) program, the effects of these changes, the source of the information used by the PO, and the additional requirements encountered with this information relative to an orbiting spacecraft. In addition, it discusses the conclusions that can be drawn from the use of the PO in an orbiting spacecraft tracking situation, such as that existing during Mariner 1971 superior conjunction.

It is appropriate to review the nature of the PO. From a hardware point of view, the PO consists of an oscillator that can be controlled remotely, a specialized interface device, a digital computer, and a special real-time pro-

gram which controls the operation of all the attendant parts. Functionally, the PO is a device which tunes a receiver to the expected carrier frequency of a spacecraft. (For a more detailed description of the PO, see Ref. 1.) The first step in this process is the development of the mathematical model or ephemeris of the spacecraft signal.

II. Orbiting Spacecraft Ephemeris and Special Constraints

An ephemeris, computed from radio metric data, is used to generate predictions of the spacecraft frequency. The program used to perform this function is called the JPL PREDICTS SYSTEM (Ref. 2). The output of this program aids the station in tracking the spacecraft.

Because of the limited I/O and memory capacity of the MAC-16 computer used to drive the PO, it is necessary to condense the input to it. The form chosen is 14th-order Chebyshev polynomial. The ephemeris produced by the JPL PREDICTS SYSTEM is converted to the polynomial form by a Sigma 5 program, TRANSPOLY, which fits the point-by-point data of the ephemeris to a closed-form interpolating function.

The orbiting of a spacecraft around Mars or any planet produces rapid changes in doppler at periapsis. The effect of these rapid changes is a doppler curve over a pass for which the derivatives do not die out fast enough. Attempting to fit a 14th-order polynomial to these data results in residual errors that exceed acceptable limits. If, however, the ephemeris for the pass is segmented into small enough parts, each part will become fittable by a 14th-order polynomial.

The PO control program pre-computes values of the ephemeris. If, in attempting to compute such a value, the program finds that the argument of time is past the range of the polynomial, it signals for the next segment. The next segment will be loaded if the actual time of loading falls within its range of arguments. This constrains the successive segments to overlap in time.

These two segmentation modifications were added to the TRANSPOLY program along with the capability to produce a configuration deck. The configuration deck specifies parameters to the PO control program about the specific tracking situation.

III. Ephemeris Information Processing

Figure 1 gives an overall view of the ephemeris information flow. There are two separate inputs to this ephemeris processing diagram. The information flow will be described, assuming that the ephemeris is available from the orbit determination program on ephemeris tapes.

The requirements for an experiment or tracking situation are determined and submitted to the Tracking Group of the Network Analysis Team (NAT TRACK) as a request for predicts. NAT TRACK is responsible for translating these requirements into parameters acceptable to the JPL PREDICTS SYSTEM 360/75 program. The requirements and the planetary and spacecraft ephemeris information are combined in this program to produce a transmission file on a mass storage device. This file contains a point-by-point tabulation of the spacecraft tracking predicts, e.g., angular position, expected trans-

mitter frequency (one- and two-way), best-lock uplink frequency, etc. When the transmission file is completed, it is dumped onto nine-track magnetic tape. This tape is copied to seven-track tape format by a utility 360/75 program so that it can be used by the Sigma 5 TRANSPOLY program for the next step in the process. The limited file space for the transmission file on the 360/75 may require the merging of several tapes into one for processing by TRANSPOLY. The program which performs this function is a Sigma 5 program called TAPMRG.

TRANSPOLY converts the information contained in the transmission file into a deck of cards containing one or more sets of polynomial constants. Furthermore, it will optionally produce the configuration deck for the Multi-Application Computer* programmed oscillator (MAC-PO).

The resulting deck of cards is further processed by the XDS 930 program EPHGEN, which converts the card images to paper tape and appends checksum information. This permits the tape to be verified for correct punching prior to its required use. When the experiment is ready to proceed, the paper tape is read and checked by the MAC-PO control program, and the information is used to control the oscillator.

IV. TRANSPOLY Program

Figure 2 shows some of the details of the TRANSPOLY program. This program is based on a 7094 FORTRAN IV SUBROUTINE package developed by C. Lawson of the Science and Engineering Computing Section. When the program is entered, it reads a control deck which specifies parameters for the run (e.g., observable(s) to be output, number of points per segment, number of points to overlap, etc.). Using this information, the program reads the Transmission file from tape, converting it to the required format. The program may optionally list the Transmission file. If an end-of-file is encountered during the reading, processing is terminated. The Transmission file format is described in Ref. 3. If the end-of-pass has not been reached, the program returns to the reading operation. When enough points have been read to delineate a segment or the end-of-pass is encountered, the program computes the fitting polynomial constants by the least-squares method. The data are fit to a 14th-order Chebyshev polynomial with uniform weighting. A configuration deck is output if required; then the appropriate polynomial constants deck is punched, together with a listing of the

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*Lockheed trade name.

residuals if desired. The program computes outputs for segments until the end-of-pass. Although it is not explicitly shown in the figure, the program will continue to run passes until the control deck signals the end of the job.

V. Modifications to the PO Program

The PO program, as initially written, assumed that the ephemeris for a pass would be in one segment only, that the doppler rate would not change sign during the pass, that the doppler excursions would be limited to 20 kHz over a pass, and that the doppler rate would not exceed 21.55 Hz/s. All of these assumptions are violated by orbiting spacecraft tracking requirements. This change in requirements necessitated the following modifications to the PO program.

The most significant change to the program is one that enables it to recognize the end of a segment and take the appropriate action. With each set of ephemeris information in polynomial form, there are parameters that give the time interval over which this set of data is valid. When the program is running, it has calculated values for the ephemeris ahead of those needed. These values lie between 96 and 128 s in the future. A new calculation is made every 32 s. When a calculation is attempted that lies outside the bounds for which the polynomial constants are valid, the program, as modified, requests the next segment of ephemeris polynomial constants. It takes 3.2 s to read the new segment into the computer. During this time, a portion of the normal processing must be suspended. The effect on the output of the PO is as follows.

During the time that the computer is reading the new data, no new control values are given to the PO control interface. Since the control value is a rate in frequency, the PO continues to track at the last rate supplied. For MM'71, the expected maximum doppler acceleration was estimated at 0.013 Hz/s^2. This represents a phase transient of at most 54 deg at S-band.

The effect of this transient on an open-loop receiver is not detectable when such a receiver is used for observing the spectra of the received signal. Its effect on a closed-loop receiver is also undetectable, since the tracking loop continues to track the signal.

After the new ephemeris has been read, normal processing is resumed, and the new data are converted for use within the computer. At the next request for a future value, the program finds that the new ephemeris set has replaced the old; therefore, the requested time is within the bounds of the ephemeris constant set, and processing continues without further interruption.

Because of the higher doppler rates and extremes encountered while tracking an orbiting spacecraft, it was necessary to change the range of control of the PO. This was accomplished by inserting the search oscillator into the next higher decade, i.e., the 1000-Hz instead of the 100-Hz decade, thus permitting the continuous tracking of doppler extremes to ±96 kHz, and doppler rates to 215.5 Hz/s. Under these conditions, the least increment of phase control is 0.18 deg.

The change in sign of the doppler rate at periapsis requires that the initial value of the search oscillator be at its midpoint. This permits the longest possible tracking time before a decade change is required of the PO.

VI. Results of PO-Assisted Tracking

The modified PO control program was employed during MM'71 superior conjunction. The output of the PO was used to control two open-loop receivers and one closed-loop receiver at the same time. The open-loop receivers measured the doppler spreading in both the left- and right-circular polarized modes. The closed-loop receiver gathered ranging information for the relativity experiment.

In order to determine the validity of the closed-loop-assisted (synchronous-assist) mode of tracking, experiments were designed to determine the effect, if any, of the PO on the doppler residuals. The uplink transmitter was interrupted for a time to ascertain the effect of loss of signal upon the doppler residuals. One round-trip light time later, it was possible to determine, from the doppler residuals alone, that loss of signal had occurred. A comparison of the doppler residuals with and without PO assistance showed no detectable difference between the two conditions.

By monitoring the performance of the closed-loop receiver, the doppler residuals, and the PO output when ephemeris segments were read into the PO computer, it was determined that no degradation of the overall performance occurred. Similar studies of the performance of the open-loop receivers also showed no degradation.

VII. Conclusions

The use of the MAC-PO to assist in the tracking of an orbiting spacecraft by a closed-loop ground receiver

has been shown to be practical and necessary. The synchronous-assist mode of receiver operation has proven successful in the tracking of high-doppler-rate signals close to the threshold of the receiver. Although the receiver was modified to permit this type of operation, none of its essential characteristics were changed (in those situations in which other tracking techniques could be applied). For example, a comparison of the doppler residuals with and without the PO assist showed no discernible effect by the PO. Also, in the absence of signal, the doppler residuals behaved in an identical way with or without the PO.

An expansion of the PO-assisted system can provide both one- and two-way tracking ability, as well as relaxing the constraints upon the ground receiver loop VCO. In the PO-assisted mode, the VCO will be required to track only the residuals of doppler (the difference between the predicted and the actual doppler), which cover a far smaller frequency range than the doppler itself. (The worst case during MM'71 was ±500 Hz at S-band or ±5.2 Hz at the VCO frequency with PO assist, compared to doppler extremes of ±26,000 Hz at S-band or ±270 Hz at the VCO frequency without PO assist.) Typical values for the residuals of MM'71 were ±15 Hz at S-band or ±0.156 Hz at the VCO frequency at periapsis during conjunction.

The use of this technique can obviate the need for more than one VCO per receiver for all tracking situations. In addition, since there is but one model predicting the doppler for a given spacecraft, one PO can provide the primary tracking information for any number of receivers assigned to a spacecraft. The PO can also aid in the acquisition of the spacecraft signal by providing real-time doppler residuals at each site.

References

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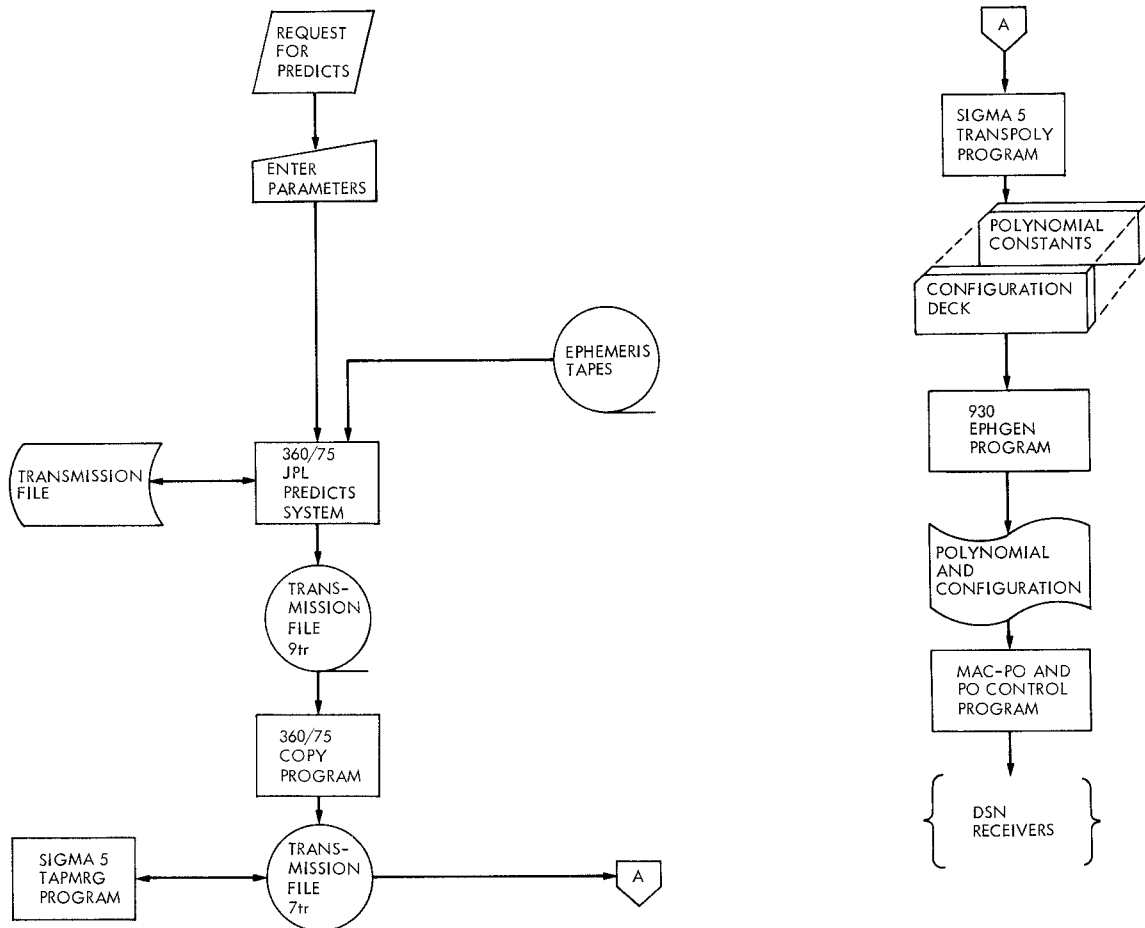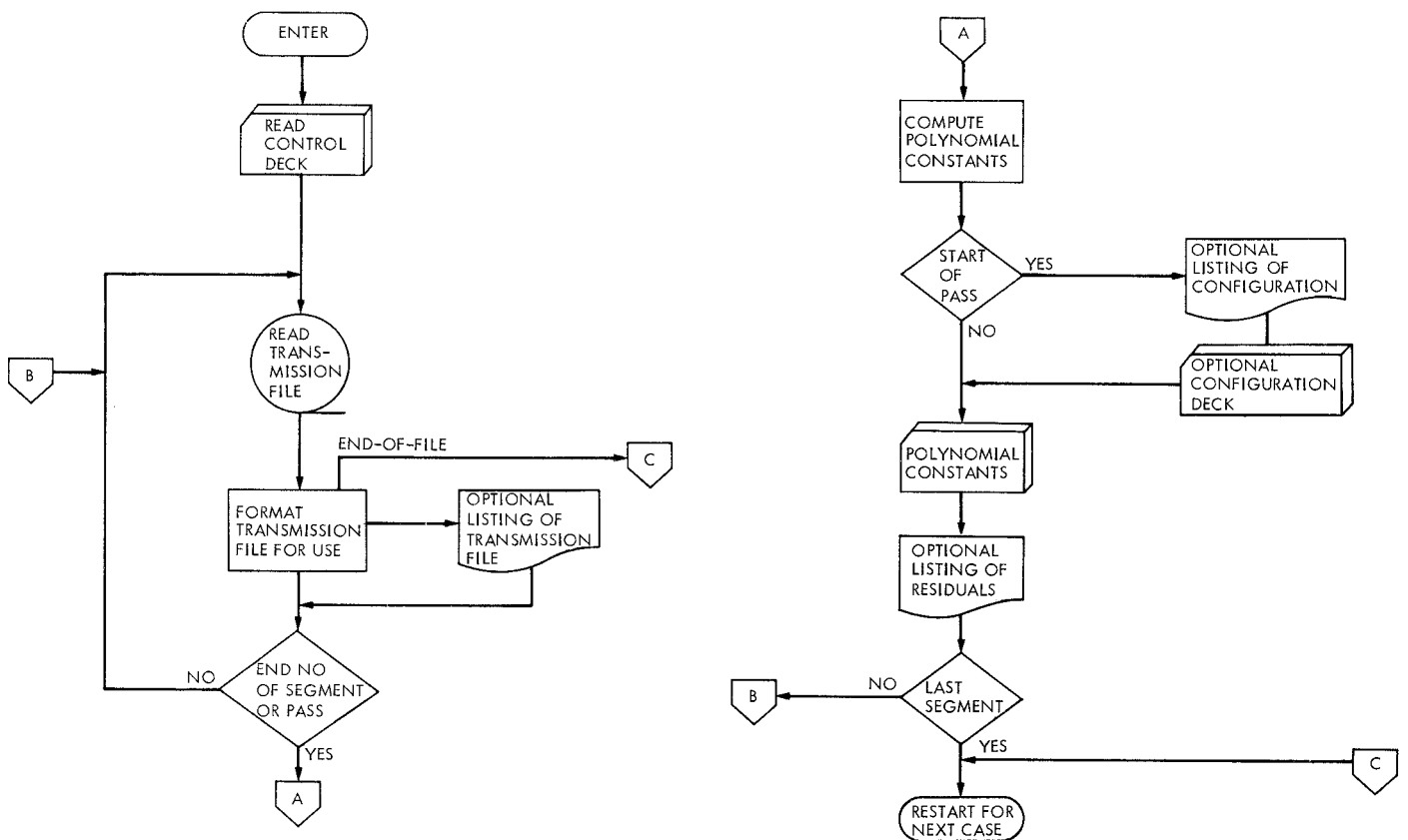
Fig. 1. Ephemeris information flow diagram

Fig. 2. TRANSPOLY block diagram